DESCRIPTION

CARRIER PHASE GPS POSITIONING DEVICE AND METHOD

5   TECHNICAL FIELD

The present invention relates to a carrier phase GPS (Global Positioning System) positioning device and method for detecting a position of a mobile station by carrier phase GPS positioning.

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BACKGROUND ART

Recently and continuing, carrier phase GPS positioning is widely used in the field of location survey. In the carrier phase GPS positioning, a receiver

15   on a reference side and a receiver on a positioning side simultaneously receive signals from a plural number of satellites, and calculate accumulated values of the carrier phases of the satellite signals at the reference side and the positioning side, separately, resulting in a

20   carrier phase accumulation value (abbreviated as "phase accumulation" if necessary, below). The thus obtained carrier phase accumulation value contains an uncertainty factor that is integral multiple of the wavelength of the carrier. This uncertainty factor is referred to as

25   "integral carrier phase ambiguity", and is often

abbreviated as "integer ambiguity".

A technique is well-known that uses a Kalman filter to determine the integer ambiguity. In this technique, a tracking filter is provided which regards the position to be determined and the integer ambiguity as state variables, a double phase difference of the phase accumulation on the positioning side relative to the reference side is an observation quantity, and each time an observation is made the state variables are updated.

There are also other techniques for determining the integer ambiguity. For example, it is known that the integer ambiguity related to a double phase difference can be found by the least-squares method under certain conditions by using the double phase difference of the carrier containing the integer ambiguity.

In the related art, if the electromagnetic wave is interrupted after the integer ambiguity is determined or in the course of the determination (also referred to as "cycle-slip"), for example, the electromagnetic wave cannot be received, one has to determine the integer ambiguity again after reception of the electromagnetic wave resumes. However, because the above techniques of the related art are proposed

specifically for positioning (determining the position of) an object which is fixed at a certain position for a long time, re-determination of the integer ambiguity is quite time-consuming.

5   To solve this problem, there is a known technique in which, after reception of the electromagnetic wave resumes, a search space is established having a radius corresponding to a positional variance with an output position of an IMU (Inertia

10 Measurement Unit) as a center, and the integer ambiguity can be determined from the number of candidates of the integer ambiguity, which are solutions in the search space. For example, Japanese Laid on Patent Publication No. 2001-99919 discloses such a technique.

15   However, in the above technique, in addition to a RTK positioning device, an IMU is also needed, and one has to calculate the variance of the position measured by the IMU alone when the electromagnetic wave is interrupted. In addition, if the electromagnetic wave

20 is cut off for a long time, the search space expends accordingly, and it is difficult to re-determine the integer ambiguity in a short duration.

DISCLOSURE OF THE INVENTION

25   Accordingly, it is a general object of the

present invention to solve the above problem of the related art.

A specific object of the present invention is to provide a carrier phase GPS positioning device capable

5   of determining and re-determining an integer ambiguity quickly and precisely, a carrier phase GPS positioning method, a carrier phase GPS positioning system, and a reference station.

According to a first aspect of the present

10   invention, there is provided a carrier phase GPS positioning device including a first integer ambiguity estimation unit that associates variance data in a first duration extracted from data received from a satellite by a reference station at a fixed position, with data

15   received from the satellite by a mobile station in a second duration shorter than the first duration, and estimates an integer ambiguity included in a carrier phase accumulation value of signals transmitted from the satellite received by the mobile station; and a

20   positioning unit that determines the position of the mobile station using the integer ambiguity estimated by the first integer ambiguity estimation unit.

According to the present invention, because the integer ambiguity is estimated by using sampling data

25   on the mobile station side in the second duration shorter

than the first duration, the time up to estimation of the
integer ambiguity is shortened. The carrier phase GPS
positioning device of the present invention can be
implemented as a mobile station receiving data from a
reference station, a reference station receiving data
from a mobile station, or a device receiving data from
both the reference station and the mobile station.

It should be noted that the variance data and
the data received by a mobile station are not necessarily
to be of the same type.

Preferably, abnormal values are excluded from
the variance data. In addition, when reception of an
electromagnetic wave emitted from the satellite is
temporarily interrupted, data prior to the interruption
is excluded from the variance data.

Preferably, the variance data in the first
duration includes a plurality of carrier phase
accumulation values of the signals transmitted from the
satellite at a first number of times in the first
duration, and the first integer ambiguity estimation unit
associates the plurality of carrier phase accumulation
values on the reference station side at the first number
of times, with a plurality of carrier phase accumulation
values on the mobile station side at a second number of
times, and estimates an integer ambiguity included in the

carrier phase accumulation values of the signals transmitted from the satellite received by the mobile station, and here the second number is less than the first number. Alternatively, the first integer ambiguity estimation unit associates the plurality of carrier phase accumulation values on the reference station side at the first number of times, with a carrier phase accumulation value on the mobile station side at one time, and estimates an integer ambiguity included in the carrier phase accumulation value of signals transmitted from the satellite received by the mobile station. In the latter case, single epoch positioning is possible.

In addition, preferably, after the first integer ambiguity estimation unit estimates the integer ambiguity, the positioning unit determines the position of the mobile station using data measured on the mobile station side alone.

Therefore, the amount of communication data between the mobile station and the reference station is greatly reduced after estimation of the integer ambiguity.

In addition, preferably, the carrier phase GPS positioning device further includes a movement quantity detection unit that detects a movement of the mobile station and a movement quantity of the mobile station when the mobile station is moving, a second integer

ambiguity estimation unit that, when the mobile station
is at rest, estimates the integer ambiguity included in
the carrier phase accumulation value of the signals
transmitted from the satellite received by the mobile

5   station. The estimation is made based on a plurality of
carrier phase accumulation values on the reference
station side and a plurality of carrier phase
accumulation values on the mobile station side at a
plurality of times in the period when the mobile station

10   is at rest, and a third integer ambiguity estimation unit
that, while the mobile station is moving, estimates the
integer ambiguity included in the carrier phase
accumulation value of the signals transmitted from the
satellite received by the mobile station while taking

15   movement detection results into consideration.

        According to the present invention, the
integer ambiguity estimation units carry out the
estimation processing in parallel and independently from
each other. Because integer ambiguities independent from

20   each other are estimated, by comparing and investigating
the integer ambiguities, an appropriate integer ambiguity
can be obtained, and this can increase precision and
reliability of the positioning.

        As an embodiment, after the second integer

25   ambiguity estimation unit or the third integer ambiguity

estimation unit estimates the integer ambiguity, the positioning unit determines the position of the mobile station using the integer ambiguity estimated by the second integer ambiguity estimation unit or the third

5   integer ambiguity estimation unit instead of the integer ambiguity estimated by the first integer ambiguity estimation unit.

Further, if the mobile station is a vehicle having wheels, the movement quantity detection unit

10   detects a movement of the vehicle based on a wheel speed sensor that detects a rotational speed of the wheels. When a slip ratio greater than a predetermined value is detected by at least the wheel speed sensor, the integer ambiguity estimation processing by the third integer

15   ambiguity estimation unit is initialized, and the positioning unit determines the position of the mobile station using the integer ambiguity estimated by the first integer ambiguity estimation unit until the third integer ambiguity estimation unit estimates or re-

20   estimates the integer ambiguity.

But when the integer ambiguity has been estimated by the second integer ambiguity estimation unit, the integer ambiguity estimated by the second integer ambiguity estimation unit may be used for determining the

25   position of the mobile station.

Because the third integer ambiguity estimation unit takes movement quantity detection results into consideration, even when the mobile station is moving, it is possible to estimate the integer ambiguity at high

5 precision.

In addition, preferably, when plural reference stations are present in a communication region, a reference station is selected which is able to communicate with more satellites in common with the

10 satellite communicating with the mobile station, and variance data related to the selected reference station are used. In addition, when there are plural reference stations able to communicate with the same number of satellites, a reference station is selected which has the

15 highest minimum reception strength of signals from the satellites. Further, when plural reference stations, which receive signals from plural common satellites and the signal reception strength of each of the common satellites exceeds a predetermined value, are present in

20 a communication region, a reference station is selected which is closest to the mobile station, and variance data related to the selected reference station are used.

Therefore, even the reference station changes along with the movement of the mobile station, reduction

25 of the integer ambiguity estimation precision is

preventable.

The carrier phase GPS positioning device of the above inventions may be installed in the navigation device of a vehicle acting as a mobile station, or other movable objects such as a working robot, a mobile phone, and a PDA, or alternatively, in a facility capable of bi-directional communication with the mobile station.

According to a second aspect of the present invention, there is provided a carrier phase GPS positioning method, including the steps of associating variance data in a first duration extracted from data received by a reference station at a fixed position from a satellite, with data received from the satellite by a mobile station in a second duration shorter than the first duration, and estimating an integer ambiguity included in a carrier phase accumulation value of signals transmitted from the satellite received by the mobile station; and determining the position of the mobile station using the estimated integer ambiguity.

According to a third aspect of the present invention, there is provided a carrier phase GPS positioning method including the steps of acquiring a carrier phase accumulation value at one time on the mobile station side; acquiring a plurality of carrier phase accumulation values at a plurality of times prior

to the one time on the reference station side;
associating the carrier phase accumulation values on the
reference station side at the plural times, with a
carrier phase accumulation value on the mobile station

5   side at the one time, and estimating an integer ambiguity
included in the carrier phase accumulation value of
signals transmitted from the satellite received by the
mobile station.

According to a fourth aspect of the present

10 invention, there is provided a carrier phase GPS
positioning system including a reference station that
extracts variance data in a first duration based on
received data from a satellite; a carrier phase GPS
positioning device including a first integer ambiguity

15 estimation unit that associates the variance data with
data received from the satellite by a mobile station in a
second duration shorter than the first duration, and
estimates an integer ambiguity included in a carrier
phase accumulation value of signals transmitted from the

20 satellite received by the mobile station; a positioning
unit that determines the position of the mobile station
using the estimated integer ambiguity; and a
communication path that enables communication between the
carrier phase GPS positioning device and the reference

25 station.

According to a fifth aspect of the present invention, there is provided a reference station that extracts variance data in a predetermined duration based on received data from a satellite, and transmits the

5   variance data to a carrier phase GPS positioning device including an estimation unit that associates the variance data with data received from the satellite by a mobile station, and estimates an integer ambiguity included in a carrier phase accumulation value received by the mobile

10   station from the satellite; and a positioning unit that determines the position of the mobile station using the estimated integer ambiguity.

According to a sixth aspect of the present invention, there is provided a reference station

15   including an acquisition unit that acquires a carrier phase accumulation value at one time on a mobile station side; an integer ambiguity estimation unit that associates a plurality of carrier phase accumulation values at a plurality of times prior to the one time on

20   the reference station side, and estimates an integer ambiguity included in a carrier phase accumulation value of signals transmitted from the satellite received by the mobile station; a positioning unit that determines the position of the mobile station using the integer

25   ambiguity estimated by the integer ambiguity estimation

unit; and a transmission unit that transmits the position detected by the positioning unit to the mobile station.

BRIEF DESCRIPTION OF THE DRAWINGS

5   These and other objects, features, and advantages of the present invention will become more apparent from the following detailed description of preferred embodiments given with reference to the accompanying drawings, in which:

10   FIG. 1 is a schematic view of a carrier phase GPS positioning device according to the present invention;

FIG. 2 is a diagram showing a configuration of the carrier phase GPS positioning device in FIG. 1;

15   FIG. 3 is a block diagram showing an embodiment of a carrier phase GPS positioning device 34 installed in the mobile station 30 according to the present invention;

FIG. 4 is a view illustrating the definitions
20   of coordinate systems used in descriptions;

FIG. 5 is a flowchart illustrating the method of determining the integer ambiguity in the carrier phase GPS positioning device 34 according to the present embodiment;

25   FIG. 6 is a flowchart illustrating the

optional processing subsequent to the routine in FIG. 5;

FIG. 7 is a flowchart illustrating an operation of determining the integer ambiguity by the time-series determination method of the related art,

5 which is performed in parallel to the routine in FIG. 5 and/or the routine in FIG. 6;

FIG. 8 is a flowchart illustrating an operation performed in the reference station 20 corresponding to the operation performed in the mobile

10 station 30 as shown in FIG. 5, FIG. 6, and FIG. 7; and

FIG. 9 is a flowchart illustrating an operation of the mobile station 30 which is capable of communicating with a number of reference stations 20.

15 BEST MODE FOR CARRYING OUT THE INVENTION

Below, preferred embodiments of the present invention are explained with reference to the accompanying drawings.

FIG. 1 is a schematic view of a carrier-phase

20 GPS positioning system according to the present invention.

As illustrated in FIG. 1, the carrier phase GPS positioning system includes GPS satellites 10 orbiting around the earth, a reference station 20 located at a fixed position (known position), and a mobile

25 station 30 that is on the earth, and is able to move on

the earth.

Each of the GPS satellites 10 broadcasts navigation messages to the earth continuously. The navigation messages include orbital information of the corresponding GPS satellite 10, clock correction value, and correction coefficients of the ionospheric layer. The navigation messages are spread using a C/A code, are carried on a L1 carrier (frequency: 1575.42 MHz), and are broadcast toward the earth.

Presently, there are 24 GPS satellites orbiting around the earth at an altitude of 20,000 km in the sky. Every four GPS satellites are equally arranged on one of six orbital planes of the earth, which are inclined by 55 degrees relative to each other. Therefore, at least five satellites are always observable from a position as long as the position is open to the sky, no matter where the position is on the earth.

FIG. 2 is a diagram showing a configuration of the carrier phase GPS positioning device in FIG. 1.

In FIG. 2, the mobile station 30 has a GPS receiver 32. In the GPS receiver 32, there is an oscillator (not illustrated) having an oscillating frequency equal to the carrier frequency of the GPS satellite 10. The GPS receiver 32 converts an electromagnetic wave, which is emitted from the GPS

satellite 10 and is received by the GPS receiver 32 via a

GPS antenna 32a, and then performs C/A code

synchronization using the C/A codes generated in the GPS

receiver 32, and extracts the navigation messages.

5   The GPS receiver 32 calculates a carrier phase

accumulation value Φ_{iu} of the carrier waves from the GPS

satellites 10_i. Here, in the phase accumulation value Φ_{iu},

the subscript i(=1, 2, …) represents the numbers assigned

to the GPS satellites 10_i, and the subscript u represents

10   that the accumulation value is calculated on the side of

the mobile station 30.

The phase accumulation value Φ_{iu} can be

described as the difference between a phase $\Theta_{iu}(t)$ of the

oscillator at the time t of receiving the carrier wave

15   and a phase $\Theta_{iu}(t-\tau)$ of the carrier wave when the

satellite signal from the GPS satellite 10_i is generated,

as shown by the following formula (1).

$$\Phi_{iu}(t) = \Theta_{iu}(t) - \Theta_{iu}(t-\tau_u) + N_{iu} + \varepsilon_{iu}(t) \qquad (1)$$

20

Here, τ_u represents travel time from the GPS

satellite 10 to the GPS receiver 32, and ε_{iu} represents

noise (uncertainty). Further, at the time when starting

observing the phase difference, the GPS receiver 32 can

25   accurately determine the carrier phase within one

wavelength of the carrier wave, but cannot determine what number of wavelengths the present wavelength is. For this reason, in the phase accumulation value $\Phi_{iu}(t)$, as shown in the formula (1), there is an uncertainty factor N_{iu},

5   known as "integer ambiguity".

The mobile station 30 also includes a communication device 33, such as a mobile phone. As described below, the communication device 33 is capable of communicating with a communication facility 23

10   installed on the reference station 20 side, such as a base station for mobile phones, by bi-directional communication.

A GPS receiver 22 having a GPS antenna 22a is installed in the reference station 20. The GPS receiver

15   22, the same as the GPS receiver 32 in the mobile station 30, calculates a carrier phase accumulation value Φ_{ib} at time t based on the carrier waves from the GPS satellites 10_i, as shown by the following formula (2).

20   $$\Phi_{ib}(t) = \Theta_{ib}(t) - \Theta_{ib}(t - \tau_b) + N_{ib} + \varepsilon_{ib}(t) \qquad (2)$$

Here, N_{ib} is an integer ambiguity, and ε_{ib} represents noise (uncertainty). In the phase accumulation value Φ_{ib}, the subscripts b represents that the

25   accumulation value is calculated on the side of the

reference station 20.

The reference station 20 transmits the obtained carrier phase accumulation value Φ_{ib} to the mobile station 30 via the communication facility 23. More

5   than one reference stations 20 may be installed in a specified region. As illustrated in FIG. 2, each of the reference stations 20 may be connected to one or more communication facilities 23 through Internet or other networks, or a communication facility 23 may be installed

10 in each of the reference stations 20. In the former case, as long as the mobile station 30 is able to communicate with the communication facility 23, the mobile station 30 can obtain the information received by each of the reference stations 20.

15   FIG. 3 is a block diagram showing an embodiment of a carrier phase GPS positioning device 34 installed in the mobile station 30 according to the present invention.

The carrier phase GPS positioning device 34 of

20 the present embodiment includes a calculation unit 40, which is connected to the GPS receiver 32 and the communication device 33, and further, to various sensors 50 in the mobile station 30. The calculation unit 40 may also be installed in the GPS receiver 32. When the mobile

25 station is a vehicle, the GPS receiver 32, the

calculation unit 40 and/or the communication device 33 may also be mounted in a navigation device.

The calculation unit 40 may be formed from a micro-computer, and may include a satellite position calculation unit 42, a movement quantity introduction unit 44, a state variable extraction unit 46, and an integer ambiguity estimation unit 48, as illustrated in FIG. 3.

The satellite position calculation unit 42, based on the orbital information in the navigation messages received by the GPS receiver 32, calculates positions $(X_i(t), Y_i(t), Z_i(t))$ of all observable GPS satellites 10_i at time t in a world coordinate system.

FIG. 4 is a view illustrating the definitions of coordinate systems used in the following description.

FIG. 4 shows relations between the world coordinate system, a local coordinate system, and a body coordinate system.

As illustrated in FIG. 4, in the world coordinate system, the origin is defined to be at the center of gravity of the earth, the X axis and Y axis, which are perpendicular to each other, are in the equatorial plane, and the Z axis is perpendicular to the X axis and Y axis.

The body coordinate system is defined on the

body of the vehicle.

Because movement of each of the GPS satellites 10 is confined to an orbital plane passing through the center of gravity of the earth, and the orbit of each of

5 the GPS satellites 10 is an ellipse with the center of gravity of the earth as a focus, positions of each of the GPS satellites 10 in the orbital plane can be calculated by successive numerical solutions of Kepler's equation.

Because the orbital planes of each of the GPS

10 satellites and the equatorial plane in the world coordinate system satisfy a rotational transformation relation, positions $(X_i(t), Y_i(t), Z_i(t))$ of the GPS satellites 10 at the time t of receiving the carrier waves can be calculated by three dimensional rotational

15 coordinate transformation of the positions of the GPS satellites 10 on the orbital planes.

The movement quantity introduction unit 44, based on the output signals of the various sensors 50 input periodically, calculates quantities related to

20 movement of the mobile station 30, and outputs the results to the state variable extraction unit 46.

For example, if the mobile station 30 is a vehicle, the movement quantity introduction unit 44 calculates the speed $Vx(t)$ (speed in the forward and

25 backward direction) and $Vy(t)$ (speed in the right and

left direction) at the time t of receiving the carrier
wave based on output signals from various sensors 50, for
example, two wheel speed sensors mounted on the driven
wheels of the vehicle, a yaw rate sensor, a left and

5 right G acceleration sensor, an azimuth meter.

Because the speed vector (Vx (t), Vy (t)) of
the vehicle is defined in the body coordinate system,
whose origin is on the body of the vehicle, it is
necessary for the movement quantity introduction unit 44

10 to transform the speed vector (Vx (t), Vy (t)) from the
body coordinate system to the world coordinate system via
the local coordinate system. Usually, the rotational
transformation of coordinates can be performed by using
Euler angles. In the present embodiment, the

15 transformation from the body coordinate system to the
local coordinate system is performed using only a yaw
angle ϕ (t) since the roll angle and pitch angle are
small. Depending on the situation, the roll angle and
pitch angle may also be considered, or the yaw angle may

20 also be ignored. The transformation from the local
coordinate system to the world coordinate system is
performed by using the longitude ϕ (t) and latitude λ (t)
of the position of the vehicle.

Specifically, assume the position of the

25 vehicle in the world coordinate system is (X_u, Y_u, Z_u),

and the longitude and latitude of the position of the
vehicle is (ϕ, λ), the speed vector of the vehicle in
the world coordinate system d/dt[X_u, Y_u, Z_u] can be
expressed by the following formula (3).

5

$$\text{d/dt[} X_u, Y_u, Z_u]^T = rot(\phi, \lambda) * rot(\phi) * [Vx, Vy]^T \quad (3)$$

Here, [ ]^T means transpose of a matrix, rot(ϕ,
λ) and rot(ϕ) are defined as the following formulae (4)

10   and (5).

$$rot(\phi, \lambda) = \begin{bmatrix} -\cos\phi\sin\lambda & -\sin\phi \\ -\sin\phi\sin\lambda & \cos\phi \\ \cos\lambda & 0 \end{bmatrix} \quad (4)$$

15
$$rot(\varphi) = \begin{bmatrix} \cos\varphi & -\sin\varphi \\ \sin\varphi & \cos\varphi \end{bmatrix} \quad (5)$$

The longitude ϕ(t) and latitude λ(t) of the
position of the vehicle may be known (fixed longitude and
latitude of a specified location which has been already
20   determined, or may be separately measured variable
longitude and latitude of the moving vehicle (that is,
the mobile station 30).

The yaw angle ϕ(t) may be calculated by
integrating a yaw angular speed (the output signal of the
25   yaw rate sensor), or may be determined by using an

azimuth meter.

In the above formula (3), by using input quantities U01, U02, and U03 on the right side, and expressing the formula in a discrete way, one obtains the following formulae (6), (7), (8).

$$X_u(t_n) = X_u(t_{n-1}) + DT*U01 \qquad (6)$$

$$Y_u(t_n) = Y_u(t_{n-1}) + DT*U02 \qquad (7)$$

$$Z_u(t_n) = Z_u(t_{n-1}) + DT*U03 \qquad (8)$$

Therefore, the final known input is expressed as below.

$$U = [DT*U01, \ DT*U02, \ DT*U03]^T \qquad (9)$$

In formulae (6), (7), (8), and (9), DT represents a sample time interval (data updating interval), and satisfies $t_n = t_{n-1} + DT$. Below, for simplicity of explanation, it is assumed that the sample time interval DT equals a period of calculating the phase accumulation value by the GPS receivers 22 and 32.

The integer ambiguity estimation unit 48 estimates the integer ambiguity by using two types of carrier phase accumulation values, that is, the carrier phase accumulation value Φ_{ib} on the side of the reference

station 20, which is received by the mobile station 30 through the communication device 33, and the carrier phase accumulation value Φ_{iu} on the side of the mobile station 30.

5   Specifically, a double phase difference of the phase accumulation of the GPS satellites 10_j and 10_h (j is not equal to h) at time t can be expressed by the following formula (10).

$$\Phi_{jhbu} = (\Phi_{jb}(t) - \Phi_{ju}(t)) - (\Phi_{hb}(t) - \Phi_{hu}(t)) \qquad (10)$$

10   On the other hand, because the distance between the GPS satellite 10_i and the GPS receiver 22 or 32 equals the wavelength L of the carrier wave multiplied by the phase accumulation value, the double phase difference Φ_{jhbu} of the phase accumulation satisfies the following formula (11).

$$\Phi_{jhbu} = \left[\left\{ \sqrt{(X_b(t) - X_j(t))^2 + (Y_b(t) - Y_j(t))^2 + (Z_b(t) - Z_j(t))^2} \right. \right.$$
$$\left. - \sqrt{(X_u(t) - X_j(t))^2 + (Y_u(t) - Y_j(t))^2 + (Z_u(t) - Z_j(t))^2} \right\}$$
$$- \left\{ \sqrt{(X_b(t) - X_h(t))^2 + (Y_b(t) - Y_h(t))^2 + (Z_b(t) - Z_h(t))^2} \right.$$
$$\left. \left. - \sqrt{(X_u(t) - X_h(t))^2 + (Y_u(t) - Y_h(t))^2 + (Z_u(t) - Z_h(t))^2} \right\} \right] / L + N_{jhbu} + \varepsilon_{jhbu} \qquad (11)$$

In formula (11), $[X_b(t), Y_b(t), Z_b(t)]$ are coordinates (known) of the reference station 20 at time t in the world coordinate system, and $[X_u(t), Y_u(t), Z_u(t)]$ are coordinates (unknown) of the mobile station 30 at time t, $[X_j(t), Y_j(t), Z_j(t)]$ and $[X_h(t), Y_h(t), Z_h(t)]$ are

coordinates of the GPS satellites 10_j and 10_h at time t calculated by the satellite position calculation unit 42. N_{jhbu} represents the double phase difference of the integer ambiguity, that is, $N_{jhbu} = (N_{jb} - N_{ju}) - (N_{hb} - N_{hu})$.

5   The integer ambiguity estimation unit 48 deduces double phase differences Φ_{jhbu} by using the formula (10) for each of four or more combinations of two GPS satellites 10_j and 10_h, thereby obtaining relations satisfying the formula (11) by substituting the deduced

10   double phase differences Φ_{jhbu} into the formula (11). For example, when five GPS satellites 10_1 to 10_5 are observable, with the GPS satellite 10_1 as a reference satellite, Φ_{12bu}, Φ_{13bu}, Φ_{14bu}, Φ_{15bu} are substituted into the formula (11) and four relations are obtained.

15   In this way, from the time of starting signal reception and periodically thereafter, that is, at time t $= t_1$, t_2, ... t_n, the integer ambiguity estimation unit 48 deduces the double phase differences Φ_{jhbu} by using the formula (10) and gives relations satisfying the formula

20   (11) at each time of t_1, t_2, ... t_n. Then, the integer ambiguity estimation unit 48 calculates the variance of ε_{jhbu} on many data samples over a long time period (from t_1 to t_n), for example, by the Kalman filter, least squares method or other estimation techniques, and

25   determines integer ambiguities N_{ju}, N_{hu} (this processing

is described below in detail with reference to FIG. 7).

In other words, the integer ambiguity estimation unit 48

needs to store the double phase differences Φ_{jhbu} at each

time before the integer ambiguities N_{ju}, N_{hu} are

5   determined. Further, the integer ambiguities N_{ju}, N_{hu}

related to the reference station 20 have already been

determined on the side of the reference station 20, and

are known quantities. The integer ambiguity estimation

unit 48 acquires the integer ambiguities N_{ju}, N_{hu} related

10   to the reference station 20 by communications. After the

integer ambiguities N_{ju}, N_{hu} are determined, by well-known

interferometric positioning methods, accurate coordinates

of the mobile station 30 can be deduced.

In practical measurements, however, because of

15   interruption of the electromagnetic wave, the

communication between the GPS satellite 10_i and the GPS

receivers 22 or 32 may be interrupted sometimes. In this

case, it is necessary to re-determine the integer

ambiguity, and it is desired that the re-determination of

20   the integer ambiguity be completed in a time period as

short as possible.

However, in the aforementioned method, many

data samples over a long time period from t_1 to t_n, are

needed to determine the integer ambiguity, and hence the

25   re-determination of the integer ambiguity is quite time-

consuming, for example, 60 seconds or so. This problem occurs not only when communication with the GPS satellite is interrupted during measurements, but also at the time when the measurement is started.

5   In contrast, by the method of determining the integer ambiguity of the present embodiment, as described below, it is possible to re-determine the integer ambiguity in a short time.

Below, the method of determining the integer 10   ambiguity of the present embodiment is explained with reference to the accompanying drawings. For clarity, the aforementioned method is referred to as "time-series determination method" to be distinguished from the method of the present embodiment.

15   FIG. 5 is a flowchart illustrating the method of determining the integer ambiguity in the carrier phase GPS positioning device 34 (specifically, the integer ambiguity estimation unit 48) according to the present embodiment. It is assumed that in addition to the routine 20   in FIG. 5, the integer ambiguity estimation unit 48 is able to execute processing in the time-series determination method and processing of calculating the position of the mobile station 30 after the integer ambiguity is determined.

25   In step S100, when the electromagnetic wave is

interrupted, or when the ignition switch of the vehicle is switched ON, the routine in FIG. 5 is initiated. Here, "electromagnetic wave interruption" means a state in which the GPS receiver 32 in the mobile station 30 can no longer receive signals required for positioning from the GPS satellites 10 (that is, the phase accumulation value becomes discontinuous, also referred to as "cycle-slip"). In this case, it is substantially not possible to execute processing in the aforesaid time-series determination method and processing of calculating the position of the mobile station 30 after the integer ambiguity is determined.

In step S105, if the electromagnetic wave is interrupted, the routine proceeds to step 110 after the reception of signals from the GPS satellites 10 is resumed (in this example, assume the timing of proceeding to step 110 is $t = t_n$).

If the ignition switch of the vehicle is switched ON, the routine proceeds to step 110 immediately.

In step S110, the phase accumulations $\Phi_{ib}(t_{n-a})$, ..., $\Phi_{ib}(t_n)$ prior to $t = t_n$ (here, from t_{n-a} to t_n), which are calculated on the side of the reference station 20, are input to the integer ambiguity estimation unit 48. For example, these data may be acquired by sending an appropriate request signal from the mobile station 30.

Alternatively, if the mobile station 30 is continuously receiving signals from the reference station 20, the integer ambiguity estimation unit 48 may read these data from a memory in the mobile station 30. In the latter case, the phase accumulation data prior to the present time, that is, $\Phi_{ib}(t_{n-a})$, ..., $\Phi_{ib}(t_{n-1})$ may also be read out.

In the step S120, at the time t when the signal reception is resumed (in this example, assume t = t_n), the phase accumulation value $\Phi_{iu}(t_n)$ on the side of the mobile station 30 is input to the integer ambiguity estimation unit 48.

In the step S130, the integer ambiguity estimation unit 48 determines or re-determines the integer ambiguity based on the phase accumulation values obtained in the step S110 and S120. In this step, a method is employed to determine the integer ambiguity, which is different from the aforesaid time-series determination method in combinations of the phase accumulation values Φ used in deduction of the double phase differences of the phase accumulation values.

Specifically, in the step S130, for example, the double phase differences Φ_{jhbu} related to two GPS satellites 10_j and 10_h (j is not equal to h) can be deduced by using the following formula (12).

$$\Phi_{jhbu} = (\Phi_{jb}(t_k) - \Phi_{ju}(t_n)) - (\Phi_{hb}(t_k) - \Phi_{hu}(t_n)) \qquad (12)$$

In detail, in formula (12), the phase
accumulation values $\Phi_{ib}(t_{n-a})$, ..., $\Phi_{ib}(t_n)$, which are
obtained in step S110, are substituted into $\Phi_{jb}(t_k)$,
respectively, and the phase accumulation values $\Phi_{hb}(t_{n-a})$,

5 ..., $\Phi_{hb}(t_n)$ obtained in step S110 are substituted into $\Phi_{jb}(t_k)$, respectively. Thus, at time $t=t_n$, a plural number
of double phase differences Φ_{jhbu} are generated (in this
example, a number of a+1 double phase differences are
generated). The $\Phi_{ju}(t_n)$ and $\Phi_{hu}(t_n)$ in formula (12) are

10 the phase accumulation values $\Phi_{ju}(t_n)$ and $\Phi_{hu}(t_n)$ at time
$t = t_n$ obtained in step S120.

Accordingly, a+1 equations are obtained by
substitution into formula (11). In formula (11), the
known coordinates of the reference station 20 at time t_{n-a}

15 to t_n are substituted into $[X_b(t), Y_b(t), Z_b(t)]$, the
known coordinates of the GPS satellites 10_j and 10_h at
time t_{n-a} to t_n are substituted into $[X_j(t), Y_j(t), Z_j(t)]$
and $[X_h(t), Y_h(t), Z_h(t)]$ with respect to the reference
station 20, respectively, known coordinates of the GPS

20 satellites 10_j and 10_h at the time of t_n (that is, $[X_j(t_n),$
$Y_j(t_n), Z_j(t_n)]$ and $[X_h(t_n), Y_h(t_n), Z_h(t_n)]$) are always
substituted into $[X_j(t), Y_j(t), Z_j(t)]$ and $[X_h(t), Y_h(t),$
$Z_h(t)]$ with respect to the mobile station 30,
respectively, and $[X_u(t), Y_u(t), Z_u(t)]$ are always the

25 coordinates (unknown) of the mobile station 30 at $t = t_n$.

These descriptions can be generally expressed by the following equation (13).

$$\Phi_{jhbu} = \left[\left\{ \sqrt{(X_b(t_k) - X_j(t_k))^2 + (Y_b(t_k) - Y_j(t_k))^2 + (Z_b(t_k) - Z_j(t_k))^2} \right. \right.$$
$$\left. - \sqrt{(X_u(t_n) - X_j(t_n))^2 + (Y_u(t_n) - Y_j(t_n))^2 + (Z_u(t_n) - Z_j(t_n))^2} \right\}$$
$$- \left\{ \sqrt{(X_b(t_k) - X_h(t_k))^2 + (Y_b(t_k) - Y_h(t_k))^2 + (Z_b(t_k) - Z_h(t_k))^2} \right.$$
$$\left. \left. - \sqrt{(X_u(t_n) - X_h(t_n))^2 + (Y_u(t_n) - Y_h(t_n))^2 + (Z_u(t_n) - Z_h(t_n))^2} \right\} \right] / L + N_{jhbu} + \varepsilon_{jhbu} \tag{13}$$
$$(t_k = t_{n-a}, \ldots, t_n)$$

Then, the integer ambiguity estimation unit 48 calculates the variance of ε_{jhbu} using these data, for example, by the Kalman filter, least squares method or other estimation techniques to determine the integer ambiguities N_{ju}, N_{hu}.

It should be noted that in the method described in the present embodiment, the data after the time $t=t_n$ are not necessary, and the integer ambiguity can be determined at the time when reception of signals is resumed or started. Hence, single epoch positioning is possible. Due to this, it is possible to quickly (instantaneously) start or resume positioning at the time of starting the vehicle or after recovery from the cycle slip.

In addition, because the integer ambiguity is an integer, in step S130, the integer ambiguity can be obtained by finding the integer solutions (that is, wave

number) closest to the real solutions obtained by the Kalman filter. For example, the LA-MBDA can be used for this purpose, which un-correlates the integer ambiguities, and narrows the searching space of the integer solutions

5   so as to facilitate finding the solutions.

After the integer ambiguities are determined, in step S140, positioning is started or re-started by well-known interferometric positioning methods (for example, kinematic positioning (RTK-GPS positioning

10 algorithm)), and accurate coordinates of the mobile station 30 can be deduced. The position of the mobile station 30 obtained in this way may be used in various controls or be presented as information, for example, they may be output and displayed on a screen of a

15 navigation device, or displayed in a map shown in a screen of a mobile phone.

As described above, according to the present embodiment, the integer ambiguity can be determined by combining data on the side of the mobile station 30 at a

20 certain time and data on the side of the reference station 20 prior to the certain time. Therefore, it is possible to quickly (instantaneously) start or resume positioning at the time of starting the vehicle or after recovery from the cycle slip.

25 In addition, in the routine illustrated in FIG.

5, it is not always necessary to obtain all the phase accumulation values from t_{n-a} to t_n, from the reference station 20, but some of the phase accumulation values may be absent. In other words, as long as a sufficiently

5   reliable integer ambiguity can be obtained in step S130, the number of the phase accumulation values obtained from the reference station 20 can be any number.

In addition, in the routine illustrated in FIG. 5, instead of obtaining the phase accumulation values

10   from the reference station 20, variance data of the phase accumulation values may be obtained. For example, If the covariance matrix created by the integer ambiguity estimation unit 48 in step 130 can be created on the side of the reference station 20 (for this purpose, it is

15   necessary to transmit the phase accumulation value $\Phi_{iu}(t_n)$ to the reference station 20), the covariance matrix may be transmitted from the reference station 20 to the mobile station 30. From the same point of view, the mobile station 30 may transmit the covariance matrix to

20   the reference station 20, the processing in step 130 and position calculation of the mobile station 30 may be executed on the side of the reference station 20, and the reference station 20 sends only the integer ambiguity and/or the position of the mobile station 30 to the

25   mobile station 30. In this case, the processing load of

the mobile station 30 can be greatly reduced, and the amount of communication data between the reference station 20 and the mobile station 30 can be greatly reduced.

5   In addition, in the routine illustrated in FIG. 5, it is exemplified that there is only one phase accumulation value ($\Phi_{iu}(t_n)$) on the side of the mobile station 30, which is used for determining the integer ambiguity, but the number of the phase accumulation

10   values on the side of the mobile station 30 may be more than one, and two or more phase accumulation values (less than a+1 in the above example) can be used in the same manner. For example, when using data after the time t = t_n, although the time required for determining the

15   integer ambiguity increases, many combinations can be obtained even with a small number of the phase accumulation values obtained from the reference station 20, and similarly, it is possible to determine a sufficiently reliable integer ambiguity.

20   In addition, in the routine illustrated in FIG. 5, for example, when five GPS satellites 10_1 to 10_5 are observable, and the cycle-slip occurs in the GPS satellite 10_2, it is not necessary to carry out the processing of re-determination of the integer ambiguity

25   for GPS satellites other than GPS satellite 10_2. In this

case, for example, for the double phase difference Φ_{12bu} of the phase accumulation values, the aforementioned formulae (12) and (13) can be used by using $\Phi_{1u}(t_n)$, $\Phi_{2u}(t_n)$. For the other double phase differences (Φ_{13bu}, Φ_{14bu}, Φ_{15bu}) of the phase accumulation values, the aforementioned formulae (10) and (11) can be used by using $\Phi_{1u}(t_{n-a})$, ... $\Phi_{1u}(t_n)$, $\Phi_{3u}(t_{n-a})$, ... $\Phi_{3u}(t_n)$. In this case, estimation of the integer ambiguities N_{ju}, N_{hu} is performed by using a combination of these data.

FIG. 6 is a flowchart illustrating the optional processing subsequent to step S140 in FIG. 5 (that is, after the time $t = t_n$). For example, the routine in FIG. 6 may be executed when the phase accumulation value $\Phi_{iu}(t_n)$ obtained in step S120, or the position of the mobile station 30 deduced based on the phase accumulation value $\Phi_{iu}(t_n)$ are apparently unreasonable, for example, the change of the position of the mobile station 30 during the cycle-slip is not practical according to the moving speed of the mobile station 30.

In step S150, at the sample time $t=t_{n+1}$ next to the time $t = t_n$, the phase accumulation value $\Phi_{iu}(t_{n+1})$, which is calculated on the side of the mobile station 30, is input to the integer ambiguity estimation unit 48. It should be noted that after the time $t = tn$, if the phase

accumulation value on the side of the mobile station 30
cannot be observed again because of the cycle slip, the
routine in FIG. 5 is carried out again.

In step S160, the phase accumulations $\Phi_{ib}(t_{n-a-1})$,
5 ..., $\Phi_{ib}(t_{n+1})$ prior to $t = t_{n+1}$ (here, from t_{n-a-1} to t_{n+1}),
which are calculated on the side of the reference station
20, are input to the integer ambiguity estimation unit 48.
For example, these data may be acquired by sending an
appropriate request signal from the mobile station 30.
10 Alternatively, if the mobile station 30 is continuously
receiving signals from the reference station 20, the
integer ambiguity estimation unit 48 may read these data
from a memory in the mobile station 30.

In step S170, the same processing as that in
15 the step S130 in FIG. 5 is performed by using the phase
accumulation value $\Phi_{iu}(t_{n+1})$. Namely, in formulae (12) and
(13), t_n is replaced with t_{n+1}. The integer ambiguity
estimation unit 48 processes these data and determines
the integer ambiguities N_{ju}, N_{hu}. In addition, in step
20 S170, estimation of the integer ambiguities N_{ju}, N_{hu} may
be performed by combining the phase accumulation values
obtained in the present step and the phase accumulation
values obtained in the previous steps. For example, if
the present routine is executed for the first time, the
25 phase accumulation values obtained previously are the

phase accumulation values obtained in step S130 in FIG. 5.
If the present routine is not executed for the first time,
the phase accumulation values obtained previously are the
phase accumulation values obtained in step S130 in FIG. 5

5   and the phase accumulation values obtained in the
previous step S170.

In step S180, the integer ambiguity previously
determined is compared with the integer ambiguity
presently obtained. For example, if it is determined that

10   the integer ambiguity obtained in step S130 is obviously
abnormal from history of the speed of the mobile station
30 during the cycle-slip, positioning can be continued
with the integer ambiguity presently obtained (refer to
step S140).

15   In step S190, step S150 to step S180 are
repeatedly executed until an integer ambiguity is
determined by the aforesaid time-series determination
method, which is executed at the same time as the present
routine (time subsequent to $t=t_n$, that is, $t=t_{n+m}$, (m=2,3,

20   ...)).

If an integer ambiguity is determined by the
time-series determination method, in step S200, the
integer ambiguities determined with the two methods are
compared with each other, and then positioning is

25   continued with the integer ambiguity determined by the

time-series determination method (that is, taking over of the integer ambiguity can be performed) by well-known interferometric positioning methods.

FIG. 7 is a flowchart illustrating an
5   operation of determining the integer ambiguity by the time-series determination method, which is performed in parallel to the routine in FIG. 5 and/or the routine in FIG. 6.

In step S300, it is determined whether the
10 mobile station 30 is moving or not. This determination may be executed by the wheel speed sensor, when the mobile station 30 is a vehicle, or image processing.

If it is determined that the mobile station 30 is at rest, the routine proceeds to step S310.

15   If it is determined that the mobile station 30 is moving, the routine proceeds to step S340.

In step S310, a static model is used to execute the time-series determination method to determine the integer ambiguity. In step S310, if the mobile
20 station 30 starts to move, the processing is stopped, and initialized. On the other hand, if the mobile station 30 is at rest until the integer ambiguity is determined, the routine proceeds to step S370. In step S370, the value of the thus determined integer ambiguity is compared with
25 the value of the integer ambiguity obtained by the

routines in FIG. 5 and FIG. 6 (refer to step S200).

In step S340, a movement model is used to execute the time-series determination method to determine the integer ambiguity. Specifically, the integer ambiguity estimation unit 48 establishes the following state equation indicated by (14) by using the known input introduced by the movement quantity introduction unit 44 (refer to formula (9)).

$$\eta(t_n) = \eta(t_{n-1}) + U(t_{n-1}) + W(t_{n-1}) \qquad (14)$$

Here, $\eta(t_n)$ is a state variable at $t = t_n$, and may represent position coordinates (unknown) of the mobile station 30 [$X_u(t_n)$, $Y_u(t_n)$, $Z_u(t_n)$], and the double phase difference of the integer ambiguity N_{jhbu}. U and W are the aforesaid known input and external noise (system noise: normal white noise), respectively. In the static model, the item of the known input $U(t_{n-1})$ in formula (14) does not exist.

In addition, the integer ambiguity estimation unit 48 also establishes the following observation equation indicated by (15), which holds also in the static model.

$$Z(t_n) = H(t_n) * \eta(t_n) + V(t_n) \qquad (15)$$

Here, Z and V represent an observation

quantity and observation noise (normal white noise),

respectively. The observation quantity Z is the double

5 phase difference of the integer ambiguity N_{jhbu}(refer to

formula (10)). While the state equation (14) is a linear

equation, the observation quantity Z is non-linear

relative to the state variable X_u, Y_u, Z_u, the items in

the formula (11) are partially differentiated relative to

10 X_u, Y_u, Z_u, thereby obtaining H in formula (15).

Therefore, if applying the Kalman filter to

the state equation (14) and the observation equation (15),

the following equations can be obtained.

For updating the time,

15 $$\eta(t_n)^{(-)} = \eta(t_{n-1})^{(+)} + U(t_{n-1}) + W(t_{n-1}) \qquad (16)$$

$$P(t_n)^{(-)} = P(t_{n-1})^{(+)} + Q(t_{n-1}) \qquad (17)$$

For updating the observation,

$$K(t_n) = P(t_{n-1})^{(-)} * H^T(t_n) * (H(t_n) * P(t_n)^{(-)} * H^T(t_n) + R(t_n))^{-1} \qquad (18)$$

20 $$\eta(t_n)^{(+)} = \eta(t_n)^{(-)} + K(t_n) * (Z(t_n) - H(t_n) * \eta(t_n)^{(-)}) \qquad (19)$$

$$P(t_n)^{(+)} = P(t_n)^{(-)} - K(t_n) * H(t_n) * P(t_n)^{(-)} \qquad (20)$$

Here, Q and R represent the covariance matrix

of the external noise and the covariance matrix of the

25 observation noise, respectively. The formulae (13) and

(19) are covariance equations. Here, the superscript $^{(-)}$ and $^{(+)}$ indicate time before and after the updating, respectively. In the static model, the item $U(t_{n-1})$ in formula (16) does not exist.

5   As a result, the estimated values of the integer ambiguity are found to be real solutions. However, since the integer ambiguity is actually an integer, the integer ambiguity is found to be an integer solution (that is, wave number) closest to the real solutions. For

10 example, the LA-MBDA can be used for this purpose, which un-correlates the integer ambiguities, narrows the searching space of the integer solutions so as to facilitate finding the solutions.

In step S350, if it is determined the slip

15 ratio of the mobile station 30 exceeds a preset value, since the reliability of the movement model (that is, the aforesaid known input) declines when the slip ratio of the mobile station 30 exceeds a preset value, the processing is stopped, and initialized in step S360. When

20 the mobile station 30 is a vehicle, the slip ratio of the mobile station 30 can be detected based on an output signal from the wheel speed sensor or accelerator sensor, as is well known in the field of the ABS control.

If it is determined that the slip ratio of the

25 mobile station 30 is does not exceed a preset value, the

routine proceeds to step 370.

In step 370, the value of the thus determined integer ambiguity is compared with the value of the integer ambiguity obtained by the routines in FIG. 5 and FIG. 6 (refer to step S200).

After the processing is stopped as shown in step S330 and S360, the integer ambiguity determined by the routines in FIG. 5 or FIG. 6 is used until the integer ambiguity is determined by either of the models.

In the processing shown in FIG. 7, when cycle slip occurs, the processing is stopped and initialized, similar to steps S330 and S360, and afterward, the integer ambiguity determined by the routines in FIG. 5 or FIG. 6 is used until the integer ambiguity is determined by either of the models.

As described above, according to the present embodiment, by introducing a movement model (that is, input a known external input U(t) to the Kalman filter), the integer ambiguity can be determined precisely even when the mobile station 30 is moving. In addition, by separately using the movement model and the static model depending on the movement condition of the mobile station 30, it is possible to improve the estimation precision of the integer ambiguity. By setting the known input to the movement model to be zero when the mobile station 30 is

at rest, the movement model alone is also sufficient.

In addition, by executing the processing in FIG. 7 in parallel to the routine in FIG. 5 and the routine in FIG. 6, the two independent integer

5 ambiguities can be compared with each other, and an appropriate integer ambiguity can be selected to be used in positioning, hence enhancing positioning reliability. From this point of view, when the GPS receivers 22 and 32 are two-frequency receivers capable of receiving both of

10 the L1 wave and L2 wave emitted from the GPS satellite 10, for each of the L1 wave and L2 wave, the same estimation processing can be performed in parallel simultaneously. In this case, because the sum of the periods of the two sides (Wide-Lane) can be created, and thereby, it is

15 possible to further narrow the range of the candidates of the integer solutions.

FIG. 8 is a flowchart illustrating an operation performed in the reference station 20 corresponding to the operation performed in the mobile

20 station 30 as shown in FIG. 5, FIG. 6, and FIG. 7.

In step S400, as a routine process, each of a number of reference stations 20 stores and manages the phase accumulation values Φ_{ib}, which are measured based on the satellite signals from each of the GPS satellites

25 10_i, in correspondence to each of sample times and each

of the GPS satellites 10_i. This treatment may be executed by a center facility (not illustrated) which controls the GPS satellites 10_i.

In step 410, as long as the cycle slip does

5   not occur concerning data related to a GPS satellite 10_k, the processing in step 400 is performed continuously. Of course, each time new data are created, data prior to a certain time can be deleted sequentially. In addition, integer ambiguity N_{ib} between each of the reference

10   stations 20 and each of the GPS satellites 10_i can be introduced into processing of step 400, which is at an initial stage. Each of the reference stations 20 may determine the reliability of the obtained phase accumulation value Φ_{ib}, and, for example, if abnormal

15   values exist, it may be required not to store the abnormal values, or not to transmit the abnormal values to the mobile station 30.

The data stored and extracted in step S400 may be transmitted to the mobile station 30 via the

20   communication facility 23 upon receiving a request signal from the mobile station 30, as described in step S110. Alternatively, the data may be broadcast in each cycle of receiving signals from each of the GPS satellites 10_i.

In the former case, determination of a mobile

25   station 30 as a transmission destination is accomplished

by an ID code included in the request signal from the mobile station 30. In the latter case, the reference station 20 may send only special data to the mobile station 30 in response to the request from the mobile

5   station 30.

In step S400, if it is detected that the cycle slip occurs concerning a GPS satellite 10_k, the routine proceeds to step S420, and the reference station 20 erases data stored before the cycle slip related to the

10   GPS satellite 10_k occurs.

As described above, according to the present embodiment, it is not necessary to transmit data generated before the cycle slip occurs to the mobile station 30. Alternatively, the stored data generated

15   before the cycle slip occurs may also be held, but not to be transmitted to the mobile station 30, that is, only data generated after the cycle slip occurs are transmitted to the mobile station 30. Thus, the mobile station 30 can obtain highly reliable data from the

20   reference station 20 by just transmitting a request signal, and does not need to check the reliability of the data transmitted from the reference station 20.

FIG. 9 is a flow chart illustrating an operation of the mobile station 30 which is capable of

25   communicating with a number of reference stations 20.

In step S500, it is determined whether the mobile station 30 is able to communicate with more than one reference stations 20.

If it is determined that the mobile station 30 can communicate with more than one reference stations 20, the routine proceeds to step S510.

In step S510, the correspondence relation between the GPS satellite 10_i captured by the mobile station 30 and the GPS satellite 10_i captured by one reference station 20 is detected. At the same time, the number of the GPS satellites 10, from which both the mobile station 30 and the reference stations 20 receive signals (below referred to as "common satellite 10"), is determined.

In step S520, if it is determined that there is one reference station 20 which receives signals from the largest number of common satellites 10, the mobile station 30 adopts the data from the one reference station 20 and executes the routines illustrated in FIG. 5, FIG. 6, and FIG. 7. For example, considering the case in which the mobile station 30 can receive signals from seven GPS satellites 10_1 to 10_7, one reference station 20_1 receives signals from six GPS satellites 10_1 to 10_6, and another one reference station 20_2 receives signals from GPS satellites 10_1 to 10_5, and GPS satellites 10_8 to 10_{11},

because both the mobile station 30 and reference stations

20 receive signals from GPS satellites 10_1 to 10_6, GPS

satellites 10_1 to 10_6 are the common satellites 10, and

because in this example, the reference station 20_1

5   receives signals from the largest number (six) of common

GPS satellites 10_1 to 10_6, the reference station 20_1 is

selected.

On the other hand, if it is determined that

there are more than one reference stations 20 each of

10   which receives signals from the largest number of common

satellites 10, the routine proceeds to step 530.

In step 530, the reception strength from each

of the common satellites 10 at different reference

stations 20 are compared with each other. The reception

15   strength at different reference stations 20 can be

measured at the reference stations 20, and may be

transmitted to the mobile station 30.

In step S540, if it is determined that there

is only one reference station 20 which receives signals

20   from the common satellites 10 at a reception level higher

than a reference level, the mobile station 30 adopts the

data from the one reference station 20 and executes the

routines illustrated in FIG. 5, FIG. 6, FIG. 7. In this

case, a reference station may be selected which has the

25   highest minimum reception strength of signals from the

common satellites. In this case, the subsequent step 550 can be ignored.

On the other hand, if it is determined that there are more than one reference stations 20 each of 5 which receive signals from the common satellites 10 at the best reception condition, the routine proceeds to step S550.

In step 550, distances to the mobile station 30 from different reference stations 20 are compared with 10 each other.

In step 560, the reference station 20 having the shortest distance to the mobile station 30 is selected. As a result, the mobile station 30 adopts the data from the closest reference station 20, and executes 15 the routines illustrated in FIG. 5, FIG. 6, and FIG. 7.

As described above, according to the present embodiment, because data from the most appropriate reference station 20 are used among the common satellites 10 with which the mobile station 30 is able to 20 communicate, it is possible to prevent degradation of the integer ambiguity estimation precision and the position detection precision when the reference station 20 is changed along with the movement of the mobile station 30.

The priority order of selecting the reference 25 station 20 is not limited to the above examples (namely,

the number of the common satellites 10, reception

strength, distance), for example, under the condition

that the number of the common satellites 10 is larger

than a specified number and the reception strength

5   exceeds a minimum level, the reference station 20 closest

to the mobile station 30 may be preferentially selected.

In this case (that is, distance is preferential), it is

possible to reduce the influence of the ionospheric layer

refraction effect and tropospheric bending, and improve

10 the estimation accuracy of the integer ambiguity.

While the present invention has been described

with reference to specific embodiments chosen for purpose

of illustration, it should be apparent that the invention

is not limited to these embodiments, but numerous

15 modifications could be made thereto by those skilled in

the art without departing from the basic concept and

scope of the invention.

For example, in the above embodiments, it is

described that the Kalman filter is applied to the state

20 equation (14) and the observation equation (15), but the

least-squares or other estimation methods can also be

used for estimating state quantities.

In addition, in the above embodiments, it is

described that the double phase difference is calculated

25 to eliminate influence of the initial phase of

oscillators in the GPS receivers 22 and 32, and clock

uncertainties. Of course, single phase difference can

also be used as long as the influence of the initial

phase of oscillators in the GPS receivers 22 and 32, and

5   clock uncertainties can be eliminated. In addition, in

the above embodiments, the influence of the ionospheric

layer refraction effect, tropospheric bending effect, and

multi-path are not considered, but the present invention

is also applicable when considering these effects.

10   In the above, for simplicity, the GPS

satellite 10_1 is regarded as a reference satellite, but

depending on the positions of the mobile station 30 and

the reference station 20, any other GPS satellites 10 may

also be used as the reference satellite. In addition, as

15   long as there are four or more double phase differences

which are related to GPS satellites common to the mobile

station 30 and the reference station 20, any combination

of the GPS satellites can be used for calculating the

double phase differences.

20   In the above embodiment, a vehicle is raised

as an example of the mobile station 30. The mobile

station 30 may also include a folk lift or a robot with

the receiver 32 and/or the calculation unit 40, and a

mobile

25   mobile phone or PDA with the receiver 32 and/or the

calculation unit 40.

According to the carrier phase GPS positioning device of the present invention, it is possible to determine an integer ambiguity quickly and precisely.

5   This patent application is based on Japanese Priority Patent Application No. 2003-403640 filed on December, 2, 2003, the entire contents of which are hereby incorporated by reference.